TITLE

APPARATUS FOR DEACTIVATING AN ENGINE VALVE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. provisional patent application Serial No. 60/416,620 filed October 7, 2002.

BACKGROUND OF THE INVENTION

The present invention relates generally to lost motion devices for internal combustion engine valve controllers and, in particular, to a spool valve lost motion valve deactivation apparatus with an integral accumulator.

Internal combustion engines are well known. Internal combustion engines include a valvetrain having intake and exhaust valves disposed in the cylinder head above each combustion cylinder. The intake and exhaust valves connect intake and exhaust ports with each combustion cylinder. The intake and exhaust valves are generally poppet-type valves having a generally mushroom-shaped head and an elongated cylindrical stem extending from the valve head. A spring biases the valve head in a fully closed position against a valve seat in the cylinder head. Historically, engine valves were actuated from the fully closed position to a fully open position by an underhead camshaft, pushrod, and rocker arm assembly. Hydraulic lifters, which utilize pressurized hydraulic fluid to actuate a piston to reciprocate the valve, were added as a buffer between the motion of the rocker arm and the valve stem and as a means for adjusting valve lash. In later developments, overhead camshafts eliminated the pushrod and, occasionally, the rocker arm for a more direct actuation of the valves.

Devices for deactivating engine valves, known in the art as lost motion devices, are also well known. Lost motion devices are advantageous because they increase the efficiency of the engine by either completely eliminating or reducing the stroke of the valve, thereby allowing no or reduced fuel-air mixture or engine exhaust to enter or exit the cylinder respectively. Many prior art hydraulic lost motion devices are capable of reducing the lift and/or duration of a cam lobe event which is transmitted to the engine valve. These devices are typically controlled by a solenoid valve, and the loss of cam motion is accomplished by the dumping of oil out of a hydraulic link between the cam

and the valve in a controlled manner. This has two primary disadvantages which have made these systems unacceptable for volume production. The first disadvantage is energy consumption, since the oil is typically pumped by the cam through a small solenoid valve, with excessive energy losses. This energy is taken out of the crank, and results in a fuel economy loss. The second failing of most lost motion systems is that because the devices use only a portion of the cam lobe, the opening and closing ramps are lost, which results in unacceptably high opening and closing acceleration rates, causing noise, wear, valve bounce, and high frequency stresses. Another concern with prior art lost motion devices is the hydraulic pressures at which they must operate, inevitably making the control solenoid large, causing high power consumption, and rendering the solenoid unable to open against extremes of oil pressure.

In addition, there is an increased interest in the ability of modern microcontrollers to control added engine valve events beyond those of a conventional camshaft, for example, to operate homogeneous charge compression ignition (HCCI) engines, to controlling diesel NOx emissions, and for compression brakes. In the case of NOx control, the strategy is to add an extra intake valve event during the exhaust stroke, or an added exhaust valve event on the intake stroke for the purpose of delivering added residual gas to the next combustion event. In the case of the compression brake, the strategy is to modulate an exhaust valve event at the top of the compression stroke to dump the compression energy to serve as a retarder. In the case of HCCI, one strategy for the control of HCCI ignition is to deliver exhaust to the cylinder in modulated amounts (extra exhaust event on the intake stroke) to control the cylinder temperature and possibly active radical chemistry as an ignition timing control.

It is desirable, therefore, to provide a lost motion apparatus that is adapted to provide a full valve event (the conventional valve event as well as the added event), to provide deactivation of the valve event (as when residual is not required) or to provide accurate modulation between these extremes for controlling the residual rate.

SUMMARY OF THE INVENTION

The present invention concerns an apparatus for deactivating an engine valve. The apparatus includes an accumulator sleeve slidably retained in an engine block and biased toward a lower chamber formed in the engine block. An interior of the sleeve is in fluid

communication with the lower chamber. A follower piston is slidably retained in the sleeve for contact with at least one lobe of a cam. An upper piston is slidably retained in an upper chamber formed in the engine block for contact with a pushrod. A fluid passage is formed in the engine block and is in fluid communication between the lower chamber and the upper chamber. A spool valve is disposed in the fluid passage and includes a control spool for opening and closing the spool valve, the control spool being biased to a valve open position. A passage is formed in the engine block and provides fluid communication between the lower chamber and one end of the control spool. A spring chamber is formed in the engine block and provides fluid communication between an opposite end of the control spool and a source of pressurized fluid.

The apparatus in accordance with the present invention advantageously provides a full lift operation, wherein the apparatus provides a full valve event including the conventional valve event as well as the added residual event. The apparatus also provides a no lift operation, as when the residual event is not required. The apparatus also provides a partial lift operation, providing accurate modulation between the full lift operation and the no lift operation outlined above.

In addition, the apparatus in accordance with the present invention accomplishes valve control in a robust and cost-effective way, without using excessive energy, which adversely impacts fuel economy. The apparatus may or may not be utilized with an EGR cam lobe on the camshaft. Preferably, an apparatus in accordance with the present invention is attached to each valve of the engine. Since the apparatus in accordance with the present invention uses the opening and closing ramps of the cam lobe there is no concern of valve-closing noise or wear, and does not require additional noise-dampening devices. Since the flowing control oil is not forced through a small solenoid orifice, either during normal operation or lost motion, the hydraulic losses are minimal. Since the solenoid is only controlling pilot flow, losses are small there as well. And since the solenoid flow area is small, pressure loads are small, and a relatively small package and power consumption is possible. Since the valve lifting pressure provides the force to close the spool, there is no need for an extra hydraulic supply to operate the system. Energy is recovered during the lost motion, and the use of a roller follower makes mechanical losses at the cam minimal.

DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a fragmentary schematic partial cross-sectional view of a valve deactivation apparatus in accordance with the present invention installed in an engine block;

Fig. 2 is an enlarged view of a portion of the apparatus shown in Fig. 1; and

Fig. 3 is fragmentary schematic partial cross-sectional view of an alternative embodiment of a valve deactivation apparatus in accordance with the present invention installed in an engine block.

DESCRIPTION OF THE PREFERRED EMBODIMENT

There is shown in Figs. 1 and 2 a spool valve lost motion deactivation apparatus indicated generally at **8** that has a longitudinal axis of operation **9**. The apparatus **8** is preferably adapted to be integrated into a valve train of an internal combustion engine and includes a follower piston **10** that is in contact with and follows the motion of a cam lobe **11** formed on a cam **12**. The follower piston **10** is slidably disposed in an accumulator sleeve **13**. The accumulator sleeve **13** includes a lower portion **13a** having a first diameter and an upper portion **13c** having a second diameter, larger than said first diameter. The portions **13a** and **13c** are connected by an angled portion **13b**. The apparatus **8** also includes a spool valve **14** that controls fluid communication between the interior of the sleeve **13** and an upper chamber **15**. An upper piston **16** slides in the chamber **15** along the axis **9** to reciprocate a pushrod **17**. The valve **14** has a spool body **18** with one end slidably retained in a first passage **19** that is in fluid communication with a lower chamber **20** open to the upper portion **13c** of the sleeve **13**. A solenoid control valve **21** selectively connects a lube oil supply passage **22** with the opposite end of the spool body **18**. The spool valve is biased to an open position by a return spring **23**. The apparatus **8** controls the actuation of the pushrod **17** by the cam **12**.

The upper chamber **15**, the first passage **19** and the supply passage **22** are all formed in surrounding engine component **24**, which can be a cylinder head or an engine block, depending on the configuration of the engine. The upper edge of the upper portion

13c of the accumulator sleeve **13** abuts a stop **25** formed by a downwardly facing wall surrounding a lower end of the lower chamber **20**. The sleeve **13** is biased upwardly by a return spring **26** that surrounds the lower portion **13a** and is retained between the accumulator angled portion **13b** and a retainer **27**. The retainer **27** has an annular shape and is mounted at a lower open end of a sleeve cavity **28** formed in the engine component **24**. The cavity **28** extends to the wall **25**. The spring **26** is preloaded to a value greater than that seen at peak lift during normal valve operation, discussed in more detail below, so that it is not moved during such normal operation.

The lower chamber **20** is open at a lower end to the upper end of the sleeve cavity **28**. A second passage **29** is formed in the engine component **24** and connects an upper end of the lower chamber **20** with a lower end of an upper chamber **15** formed in the engine component **24**. A third passage **30** formed in the engine component **24** extends from the lower chamber **20** to the first passage **19**. The first passage **19** extends transverse to the longitudinal axis **9** and is connected to the second passage **29** between the upper and lower ends thereof. The first passage **19** slidably receives a first portion **18a** of the spool body **18**. A spring chamber **31** formed in the engine component **24** receives a second portion **18b** of the spool body **18** and extends from the second passage **29** diametrically opposed to the first passage **19**. The return spring **23** is disposed in the spring chamber **31**.

The lube oil supply passage **22** extends between the upper chamber **15** and a source of pressured oil (not shown) and includes a check valve **32** disposed therein to permit oil flow only into the upper chamber **15**. A valve inlet passage **33** and a valve outlet passage **34** are formed in the engine component **24** and are connected between the oil supply passage **22** the valve **21** and between the valve **21** and the spring chamber **28** respectively. In operation, the interior of the sleeve **13**, the lower chamber **20**, the first passage **19**, the second passage **29**, the third passage **30**, the upper chamber **15**, the lube oil supply passage **22**, the valve inlet passage **33**, the valve outlet passage **34** and the spring chamber **31** are each filled with pressured oil **P** from the lube oil supply and form a closed hydraulic system.

The upper piston **16** is slidably disposed in the upper chamber **15**. The upper piston **16** is connected to the pushrod **17**, which is connected to an engine valve (not shown). Depending on the configuration of the engine, the pushrod **17** connected to a

rocker (not shown), may be a stem of the valve (not shown), or a portion of a rocker (not shown) connected to the valve. The spool valve **14** is shown in the open position wherein the spool **18** includes a reduced diameter central **18c** disposed in the second passage **29** and connected between the first portion **18a** and the second portion **18b**. The first portion **18a** is slidably disposed in an enlarged diameter portion **19c** of the first passage **19**. The first portion **18a** has a first control surface **18d** biased against a step **19b** connecting the portion **19c** with a smaller diameter portion **19a** of the first passage **19**. The first portion **18a** has a second control surface at the connection to the central portion **18c**. The second portion **18b** has a third control surface **18f** at the connection to the central portion **18c** and a fourth control surface **18g** abutting the spring **23**. An extension **18h** extends axially from the fourth control surface **18g** for facilitating attachment of the spring **23** to the spool body **18**. The control surfaces **18d** and **18g** have substantially identical surface areas for pressure balancing the spool valve **14** as do the control surfaces **18e** and **18f**. The return spring **23** biases the spool body **18** against the oil pressure in the lower chamber **20** to open the spool valve **14** as shown in the figures. In the open position, the central portion **18c** is disposed in the second passage **29** allowing oil to flow from the lower chamber **20** and through the passage **29** to the upper chamber **15** when the follower piston **10** is moved upwardly by the cam **12**.

The valve control surface **18d**, therefore, is exposed through the third passage **30** and the first passage **19** to the pressured oil in the lower chamber **20** and the valve control surface **18g** is exposed, through the solenoid control valve **21** and the passages **33** and **34**,to lubricating oil pressure from the lube oil supply passage **22**. The solenoid valve **21**, when in an open mode, is operable to allow flow from the lube oil supply passage **22** to the spring chamber **31**. The valve control surfaces **18e** and **18f** are exposed to the lubricating oil pressure in the second passage **29**.

The operation of the lost motion deactivation apparatus **8** will now be described. In a full lift operation, the solenoid control valve **21** is closed with the spool valve **14** in an open position, which traps any lubricating oil in the spring chamber **31** and immobilizes the spool body **18**. When the cam **12** rotates in a clockwise direction and a first ramped portion **11a** of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10**, the follower piston **10** moves upwardly and displaces oil in the sleeve **13** and the lower chamber **20**. Since the spool valve **14** is open, the oil

displaced by the follower piston **10** passes through the second passage **29** and into the upper chamber **15** to move the upper piston **16** upwardly. The movement of the upper piston **16** in turn moves the pushrod **17**. As the follower piston **10** moves upwardly, the pressure in the first passage **19** tries to move the spool body **18** against the spring **23** and the oil trapped in the closed spring chamber **31** and may move the spool body **18** slightly, but will not close the valve **14**. The trapped oil in the spring chamber **31** and the closed solenoid control valve **21** prevent movement of the spool body **18** because as pressure increases on the valve control surface **18d**, the oil in the spring chamber **31** does not have an outlet and, as an incompressible fluid, cannot be displaced. The check valve **32** also prevents oil from flowing from the upper chamber **15** to the lube oil supply passage **22**, ensuring that the oil displaced in the upper chamber **15** moves the upper piston **16** and the pushrod **17**.

As the cam **12** continues to rotate, a second ramped portion **11b** of the cam lobe **11** contacts the follower piston **10**, causing the follower piston **10** to lower and lowering the pressure in the sleeve **13** and the lower chamber **20**. The lower pressure, in combination with the valve springs attached to the engine valve forcing the upper piston **16** downwardly cause the follower piston **10** to move downwardly. During the full lift operation described above, the accumulator sleeve **13** is not unloaded and remains stationary. An extra valve event, such as caused by an EGR lobe **35** on the cam **12**, operates the apparatus **8** in the same manner in a full lift operation.

In a zero lift operation, the solenoid control valve **21** is actuated to an open mode with the spool valve **14** in an open position, which allows any lubricating oil in the spring chamber **31** to flow to the lube oil supply passage **22**. When the cam **12** rotates and the first ramped portion **11a** of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10**, the follower piston **10** moves upwardly and displaces oil in the sleeve **13** and the lower chamber **20**. Since the spool valve **14** is open, the oil displaced by the follower piston **10** passes through the lower chamber **20**, the second passage **29**, and the upper chamber **15**. As the pressure in the first passage **19** rises above the pressure in the lube oil supply passage **22**, because the check valve **32** prevents oil from flowing from the upper chamber **15** into the lube oil supply passage **22**, the valve control surfaces **18d** and **18g** are exposed to different pressures and the spool body **18** is moved against the return spring **23** and the pressure from the supply passage **22**. The

first portion **18a** moves into the second passage **29** to close the valve **14** before the engine valve spring preload is reached, which isolates the upper chamber **15** from oil flow before the engine valve starts to move. After the valve **14** is closed, the lower chamber **20** and the interior of the sleeve **13** are also isolated, increasing the pressure in both as the follower piston **10** rises. The higher pressure acts on the angled surface **13b** of the accumulator sleeve **13**, eventually overcoming the preload of the spring **26** and causing the accumulator **13** to move downwardly. This high pressure may encourage the use of roller followers (not shown) to avoid normal force-driven increases in friction.

As the cam **12** continues to rotate, the second ramped portion **11b** of the cam lobe **11** contacts the follower piston **10**, causing the follower piston **10** to lower and consequently reducing the pressure in the sleeve **13** and the lower chamber **20**. As the pressure is reduced, the spring **26** moves the accumulator sleeve **13** upwardly. Eventually the spring **26** returns the energy stored by cam motion back to the cam **12** and the spring **26** returns to a rest position. When the pressure in the lower chamber **20** and the sleeve **13** is reduced, the pressure in the upper chamber **15** and the first passage **19** is also reduced. The pressure on the valve control surfaces **18d** and **18g** eventually equalizes allowing the spring **23** to return the valve **14** to the open position. At this point, only a small pilot volume of oil has flowed through the open solenoid valve **21**, and the oil to the accumulator sleeve **13** and back has not been forced to flow through an orifice. The EGR lobe **35** operates the apparatus **8** in the same manner in a zero lift operation.

In a partial lift operation, the solenoid control valve **21** is closed with the spool valve **14** in an open position, as in the full lift operation outlined above, which traps any lubricating oil in the spring chamber **31**. When the cam **12** rotates and the first ramped portion **11a** of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10**, the follower piston **10** moves upwardly and displaces oil in the sleeve **13** and the lower chamber **20**. Since the spool valve **14** is open, the oil displaced by the follower piston **10** passes through the lower chamber **20**, the second passage **29**, and into the upper chamber **15** to move the upper piston **16** upwardly. The upper piston **16** moves in response to the oil flow to drive the pushrod **17**, as in the full lift operation outlined above.

At a predetermined point in the motion of the cam **12** corresponding to the

desired lift of the engine valve is reached, the solenoid valve **21** is opened, which drives the spool body **18** to the right in Fig. 2 against the combined force of the spring **23** and the lubrication pressure from the lube oil supply passage **22**. Thus, the first portion **18a** moves into the second passage **29** and closes the valve **14**. When the valve **14** is closed, this isolates the upper chamber **15** from the lower chamber **20**, freezing the engine valve in position, and allowing the remainder of cam lift to be absorbed by the accumulator **13**, as in the zero lift operation outlined above. The valve **14** will remain closed as the follower piston **10** goes over the nose of the cam lobe **11**, and the spring **26** of the accumulator **13** returns energy as in the zero lift operation outlined above. As the cam **12** rotates, eventually a crank angle will be reached when the follower piston **10** reaches the same lift as at the crank angle when the solenoid valve **21** was opened. At this point, the pressures in the upper chamber **15** and the lower chamber **20** are again equal (as when the solenoid valve **21** was opened), and the spool valve **14** begins to open as the pressure in the lower chamber **20** and on the valve control surface **18d** drops with the closing motion of the follower piston **10** and the cam **12**. With the spool valve **14** open, the upper chamber **15** and the lower chamber **20** are in fluid communication, and the engine valve is under control of the cam **12**. This particularly includes the closing ramp **11b** of the cam lobe **11**, which advantageously assures acceptable closing velocities and accelerations of the engine valve. Modulation of the apparatus **8** will be by variation of the predetermined crank angle at which the solenoid valve **21** is opened, which will advantageously allow the lift of the cam **12** to be varied, and will allow the lift-time area under the valve motion curve to be controlled. Similar partial lift operation can be obtained with the EGR lobe **35**.

Referring now to Fig. 3, an alternative embodiment of a spool valve lost motion deactivation apparatus is indicated generally at **8'**. The apparatus **8'** is similar to the apparatus **8** of Figs. 1 and 2 and corresponding elements have the same reference numerals and are not described in detail below. The apparatus **8'** includes a three-port switching solenoid control valve **36** that selectively connects the spring chamber **31** with a lube oil supply passage **22'**, similar to the lube oil supply passage **22** of Figs. 1 and 2, and a lube oil passage **38** that extends from and is in fluid communication with the upper chamber **15**. The lube oil passage **38** does not include a check valve, such as the check valve **32** of Figs. 1 and 2.

The operation of the lost motion deactivation apparatus **8'** is as follows. In a full lift operation, the solenoid control valve **36** is in a first connection position with the spool valve **14** in an open position, wherein the spring chamber **31** is in fluid communication with the upper chamber **15** through the lube oil passage **38** and the spring chamber **31** is isolated from the lube oil supply passage **22'**. When the cam **12** rotates in a clockwise direction and a first ramped portion **11a** of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10**, the follower piston **10** moves upwardly and displaces oil in the sleeve **13** and the lower chamber **20**. Since the spool valve **14** is open, the oil displaced by the follower piston **10** passes through the second passage **29** and into the upper chamber **15** to move the upper piston **16** upwardly. The movement of the upper piston **16** in turn moves the pushrod **17**. With the solenoid control valve **36** in the first position, the lower chamber **20**, the first passage **19**, the upper chamber **15**, and the spring chamber **31** are in fluid communication with each other. The pressure of the oil in the lower chamber **20**, the first passage **19**, the upper chamber **15**, and the spring chamber **31**, therefore, is equalized and the spool body **18** remains in place in the open position because of the balanced pressures on the respective control surfaces **18d**, **18e**, **18f**, and **18g** adjacent the respective chambers and passages **19**, **20**, and **31**.

As the cam **12** continues to rotate, a second ramped portion **11b** of the cam lobe **11** contacts the follower piston **10**, causing the follower piston **10** to lower and lowering the pressure in the sleeve **13** and the lower chamber **20**. The lower pressure, in combination with the valve springs attached to the engine valve forcing the upper piston **16** downwardly, cause the follower piston **10** to move downwardly. During the full lift operation described above, the accumulator sleeve **13** is not unloaded and remains stationary. An extra valve event, such as caused by an EGR lobe **35** on the cam **12**, operates the apparatus **8'** in the same manner in a full lift operation.

In a zero lift operation, the solenoid control valve **36** is in a second connection position with the spool valve **14** in an open position, wherein the spring chamber **31** is in fluid communication with the lube oil supply passage **22'** and the spring chamber **31** is isolated from the upper chamber **15**. When the cam **12** rotates and the first ramped portion **11a** of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10**, the follower piston **10** moves upwardly and displaces oil in the sleeve

13 and the lower chamber **20**. Since the spool valve **14** is open, the oil displaced by the follower piston **10** passes through the lower chamber **20**, the second passage **29**, and the upper chamber **15**. As the pressure in the first passage **19** rises above the pressure in the lube oil supply passage **22'**, because the solenoid control valve **36** prevents oil from flowing from the upper chamber **15** into the lube oil supply passage **22'** or the spring chamber **31**, the valve control surfaces **18d** and **18g** are exposed to different pressures and the spool body **18** is moved against the return spring **23** and the pressure from the supply passage **22'**. The first portion **18a** moves into the second passage **29** to close the valve **14** before the engine valve spring preload is reached, which isolates the upper chamber **15** from oil flow before the engine valve starts to move. After the valve **14** is closed, the lower chamber **20** and the interior of the sleeve **13** are also isolated, increasing the pressure in both as the follower piston **10** rises. The higher pressure acts on the angled surface **13b** of the accumulator sleeve **13**, eventually overcoming the preload of the spring **26** and causing the accumulator **13** to move downwardly. This high pressure may encourage the use of roller followers (not shown) to avoid normal force-driven increases in friction.

As the cam **12** continues to rotate, the second ramped portion **11b** of the cam lobe **11** contacts the follower piston **10**, causing the follower piston **10** to lower and consequently reducing the pressure in the sleeve **13** and the lower chamber **20**. As the pressure is reduced, the spring **26** moves the accumulator sleeve **13** upwardly. Eventually the spring **26** returns the energy stored by cam motion back to the cam **12** and the spring **26** returns to a rest position. When the pressure in the lower chamber **20** and the sleeve **13** is reduced, the pressure in the upper chamber **15** and the first passage **19** is also reduced. The pressure on the valve control surfaces **18d** and **18g** eventually equalizes allowing the spring **23** to return the valve **14** to the open position. At this point, no oil has flowed through the solenoid control valve **36**, and the oil to the accumulator sleeve **13** and back has not been forced to flow through an orifice. The EGR lobe **35** operates the apparatus **8'** in the same manner in a zero lift operation.

In a partial lift operation, the solenoid control valve **36** is in the first connection position wherein the spring chamber **31** is in fluid communication with the upper chamber **15** through the lube oil passage **38** and the spring chamber **31** is isolated from the lube oil supply passage **22'**. When the cam **12** rotates and the first ramped portion

11a of the outer surface of the cam lobe **11** engages with a lower surface of the follower piston **10,** the follower piston **10** moves upwardly and displaces oil in the sleeve **13** and the lower chamber **20**. Since the spool valve **14** is open and the solenoid control valve **36** is in the first connection position, the oil displaced by the follower piston **10** passes through the lower chamber **20**, the second passage **29**, and into the upper chamber **15** to move the upper piston **16** upwardly. The upper piston **16** moves in response to the oil flow to drive the pushrod **17**, as in the full lift operation outlined above.

At a predetermined point in the motion of the cam **12** corresponding to the desired lift of the engine valve is reached, the solenoid valve **36** is placed in the second connection position, placing the spring chamber **31** in fluid communication with the lube oil supply passage **22'** and isolating the spring chamber **31** from the upper chamber **15** through the lube oil passage **38**. The pressure on the control surface **18g** falls below the pressure on the control surface **18d**, which drives the spool body **18** to the right in Fig. 3 against the combined force of the spring **23** and the lubrication pressure from the lube oil supply passage **22'**. Thus, the first portion **18a** moves into the second passage **29** and closes the valve **14**. When the valve **14** is closed, this isolates the upper chamber **15** from the lower chamber **20**, freezing the engine valve in position, and allowing the remainder of cam lift to be absorbed by the accumulator **13**, as in the zero lift operation outlined above. The valve **14** will remain closed as the follower piston **10** goes over the nose of the cam lobe **11**, and the spring **26** of the accumulator **13** returns energy as in the zero lift operation outlined above. As the cam **12** rotates, eventually a crank angle will be reached when the follower piston **10** reaches the same lift as at the crank angle when the solenoid control valve **36** was placed in the second connection position. At this point, the pressures in the upper chamber **15** and the lower chamber **20** are again equal (as when the solenoid control valve **36** was placed in the second connection position), and the spool valve **14** begins to open as the pressure in the lower chamber **20** and on the valve control surface **18d** drops with the closing motion of the follower piston **10** and the cam **12**. With the spool valve **14** open, the upper chamber **15** and the lower chamber **20** are in fluid communication, and the engine valve is under control of the cam **12**. This particularly includes the closing ramp **11b** of the cam lobe **11**, which advantageously assures acceptable closing velocities and accelerations of the engine valve. Modulation of the apparatus **8'** will be by variation of the predetermined crank angle at which the

solenoid control valve **36** is placed in the first and the second connection positions, which will advantageously allow the lift of the cam **12** to be varied, and will allow the lift-time area under the valve motion curve to be controlled. Similar partial lift operation can be obtained with the EGR lobe **35**.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.